International Journal of Environment and Climate Change

Volume 14, Issue 8, Page 22-28, 2024; Article no.IJECC.118196
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Derivation of Rainfall Intensity-Duration- Frequency (IDF) Curves of Gainesville, Georgia, United States

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijecc/2024/v14i84327

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here:
https://www.sdiarticle5.com/review-history/118196

Original Research Article

Received: 26/04/2024
Accepted: 28/06/2024
Published: 30/07/2024

ABSTRACT

This research presents a set of Intensity-Duration-Frequency (IDF) curves of Gainesville, Georgia, USA for duration of 15 minutes to 24 hours, and return periods of 2 to 100 years. The objective of this research focuses on the development of IDF curves for the Gainesville, Georgia, USA. Gumbel and Log Pearson Type III models were used to develop the IDF curves. The best rainfall model between Log Pearson III and Gumbel model for the predication of rainfall in the study area was determined for the different return periods and durations. The Gumbel and Log Pearson Type III distributions give maximum intensities of 138.17 mm/hr and 137.75 mm/hr at return period of 100 years with duration of 0.25 hours, respectively. The result of this study can be used by water resource planners and managers for the city of Gainesville, Georgia.

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Cite as: *Sileshi, R., and S. Panda. 2024. "Derivation of Rainfall Intensity-Duration- Frequency (IDF) Curves of Gainesville, Georgia, United States". International Journal of Environment and Climate Change 14 (8):22-28. https://doi.org/10.9734/ijecc/2024/v14i84327.*

Keywords: IDF curves; gumbel distribution; log pearson type III distribution.

1. INTRODUCTION

Intensity-Duration-Frequency (IDF) curves are widely used to evaluate rainfall events, to derive design storms and assist in designing drainage structures, culverts, bridges, and other hydraulic structures [1-4]. These IDF curves play a significant role in designing various water resources infrastructure. In order to estimate these runoff magnitudes, IDF curves are the typical hydrologic tools used by water resources, agricultural, and civil engineers. IDF curves represent a mathematical function that relates the rainfall intensity *i*, with its duration *d* and the return period T [5,6]. The IDF curve illustrates the relationship between mean precipitation intensity, rainfall duration, and return period [7].

Developing IDF curves for most countries around the globe is a major problem because of the limited availability of sufficient long-term rainfall data [6,8]. There are several methods that can be used to generate rainfall IDF curves. Gumbel, Pearson Type III, and Log normal distributions are commonly used distributions in IDF studies [9]. [10] found that Gumbel and Log Pearson Type III distributions fitted well to measured data compared to Log-normal distribution.

The objective of this research is to develop IDF curves for the Gainesville, Georgia, USA. Two different frequency distributions namely the Gumbel and the Log-Pearson Type III distributions were fitted to the rainfall data for selected return periods (2 to 100 years) and durations (0.25, 0.5, 0.75, 1, 2, 6, 12 and 24 hours).

2. MATERIALS AND METHODS

2.1 Study Area

The city of Gainesville is located in central Hall County, Georgia, United States at 34°18′16″N 83°50′2″W (Fig. 1). The city has a total area of 91.48 km^2, of which 86.43 km^2 are land and 5.05 km^2, or 5.52%, are water [11]. The average annual temperature in Gainesville is 15.5^{o}C [12]. The average monthly temperature ranges from 5.1^{o}C in January to 25.4^{o}C in July, with variation in temperature. The average annual precipitation during 1991–2020 was 1411.2 mm.

2.2 Data Collection and Analysis

In this study, 15 minutes to 24 hours rainfall data from Dawsonville, Georgia rain gauge station located at Latitude: 34.4206 and Longitude: -84.1039 has been selected for determination of IDF curves of Gainesville, Georgia. The station is located about 37 km from the study area. Historic rainfall data (Fig. 2) from 1978 to 2004 (26 years) for Dawsonville was obtained from U.S NOAA National Weather Service Hydrometeorological Design Studies Center [14]. Precipitation Frequency Data Server was used to develop the IDF curves for this study.

From the data base, the annual extreme values of precipitation for selected durations (15 minutes to 24 hours) were extracted for Dawsonville, GA for each year. Precipitation analyses were performed for eight rainfall durations, and six return periods (2, 5, 10, 25, 50, 100 years). Gumbel and Log-Pearson Type III distributions were used for these analyses. The rainfall intensity (the time rate of precipitation-mm/hr or in/hr), i_T for the return period T is obtained from equation 1.

$$i_T = \frac{x_T}{T_D} \quad (1)$$

Where i_T: rainfall intensity, mm/hr

x_T: rainfall depth in mm

T_D: rainfall duration in hours for Gumbel distribution

2.3 Gumbel Distribution

Gumbel [15] presented the theory of extremes by considering the distribution of the largest or the smallest values for a set of samples of different distributions. Gumbel is the most commonly used method for IDF analysis due to its appropriateness for modelling of maximum data. The following equation is used to express the design rainfall depth for a given period [16].

$$x_T = \bar{x} + K_T s \quad (2)$$

x_T: rainfall depth in mm
$\bar{x}$: average of annual precipitation data
s: sample standard deviation of rainfall data
K_T: is the Gumbel frequency factor given by equation 3
T: return period

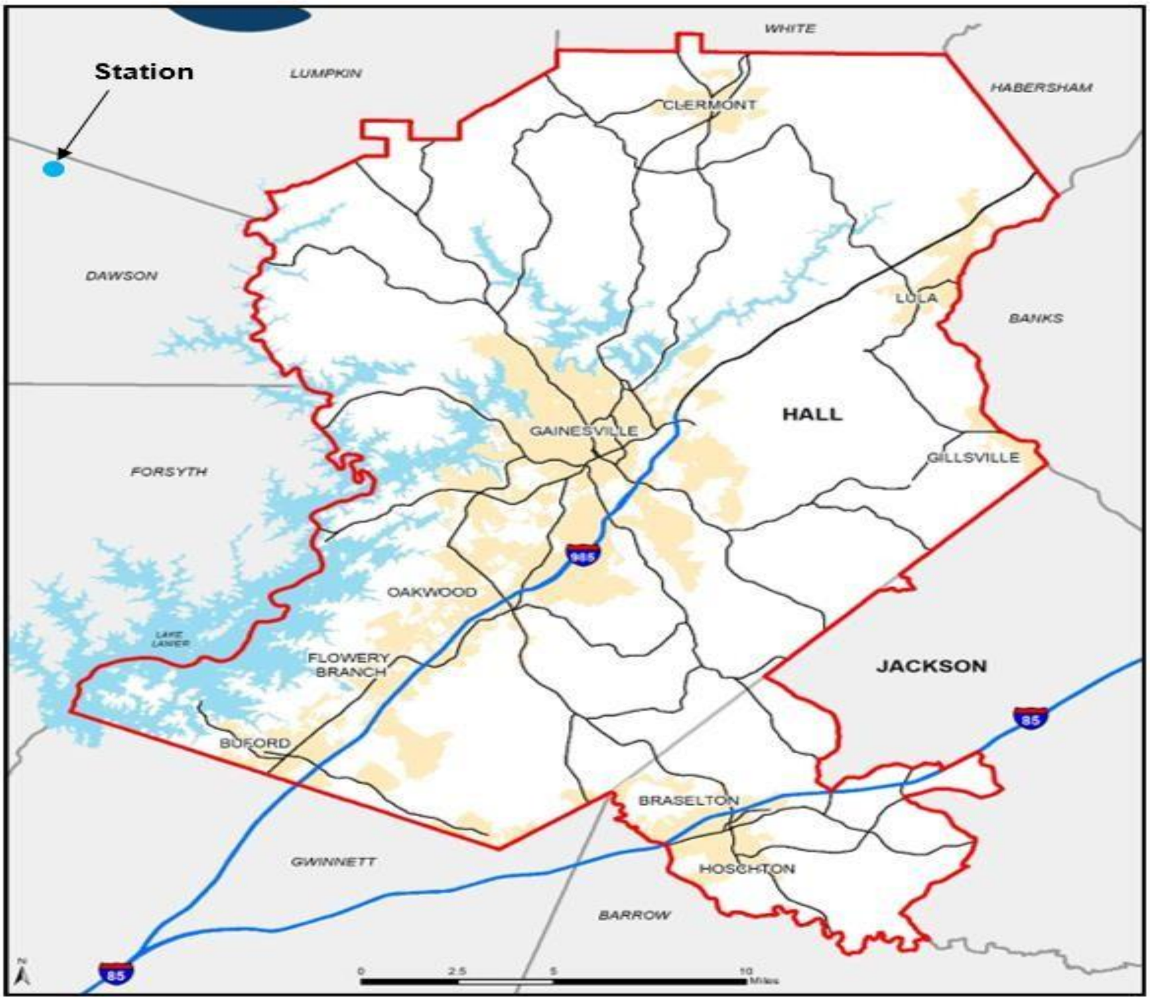

Fig. 1. Map showing location of the study area [13]

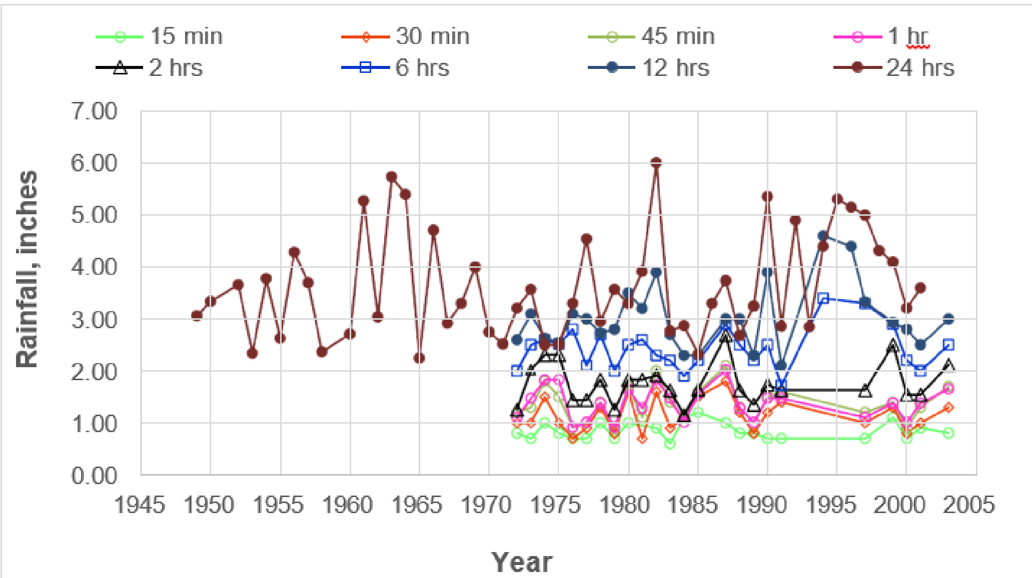

Fig. 2. Annual precipitation of Dawsonville, GA (1945–2005)

The Gumbel frequency factor, K_T *is* calculated using equation (3).

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\} \quad (3)$$

2.4 Log Pearson Type III (LPT III) Distribution

The frequency precipitation for Log Pearson Type III model can be obtained by the same approach as Gumbel distribution method (equation 2), but the mean and the standard deviation (*s*) are determined based on the natural logarithms of the original data values as shown in the equation (4) [9,2,17]. The frequency factor, K_T in this distribution is a function of both the return period (*T* in years) and the skewness coefficient. In the LPT III method, frequency factors, K_T values can be determined from standard tables [18,19]. K_T values have been determined for the desired return periods by making a set of interpolation between values of standard table.

$$\log x_T = \overline{\log x} + K_T S_{\log x} \quad (4)$$

Where:

$\log x_T$: logarithm of precipitation depth with specified return period *T* (in years)
$\overline{\log x}$: average of logx values
$S_{\log x}$: standard deviation of $\log x$ values, and

3. RESULTS AND DISCUSSION

Computed values frequency factors, K_T (for return periods, T = 2, 10, 25, 50, and 100 years) and the rainfall amounts (mm/hr) with respect to specific durations used in Gumbel distribution are given in Table 1. In Gumbel method the K_T values increase with rise of the return period for any rainfall duration (Table 1).

The frequency factor, K_T in the Log Pearson Type III method is a function of both the return period and the skewness coefficient. Calculated values of K_T for six return periods in Log Pearson Type III distribution are given in Table 2. The intensity values (mm/hr) for eight durations and six return periods using Log Pearson III method are presented in Table 3.

Table 1. Calculated K_T and rainfall values (mm/hr) using Gumbel distributions

	Return Periods, T					
	2	**5**	**10**	**25**	**50**	**100**
Duration (hr.)	**Frequency Factors, K_T**					
	-0.1600	0.7200	1.3000	2.0400	2.5900	3.1400
0.25	82.950	97.730	107.520	119.890	129.070	138.170
0.5	55.410	69.350	78.580	90.240	98.890	107.480
0.75	44.540	54.660	61.360	69.830	76.110	82.340
1	33.620	40.830	45.600	51.640	56.120	60.560
2	21.500	26.000	28.980	32.750	35.540	38.310
6	10.050	11.600	12.620	13.920	14.880	15.830
12	6.150	7.330	8.100	9.090	9.810	10.540
24	3.670	4.610	5.240	6.030	6.610	7.190

Table 2. Log-Pearson frequency factors, K_T for various durations and return periods

		Frequency Factor, K_T					
Rainfall Duration (hr.)	**Skewness Coff. (*G*)**	Return Periods, T					
		2	**5**	**10**	**25**	**50**	**100**
0.25	0.370	-0.060	0.820	1.310	1.870	2.250	2.600
0.5	0.010	0.000	0.840	1.280	1.750	2.060	2.330
0.75	-0.030	0.000	0.840	1.280	1.740	2.040	2.310
1	-0.100	0.020	0.850	1.270	1.720	2.000	2.250
2	0.240	-0.040	0.830	1.300	1.830	2.180	2.500
6	0.140	-0.020	0.830	1.300	1.800	2.130	2.430
12	0.580	-0.100	0.800	1.330	1.930	2.350	2.740
24	0.300	-0.050	0.820	1.310	1.850	2.210	2.540

Table 3. Calculated rainfall values using log pearson type iii distribution

Rainfall	Return Period, T					
Duration (hr.)	2	5	10	25	50	100
0.25	83.230	98.340	108.050	120.080	128.950	137.750
0.5	55.960	70.420	79.420	90.300	98.120	105.710
0.75	45.140	55.550	61.870	69.370	74.680	79.770
1	34.180	41.590	45.990	51.120	54.670	58.040
2	21.620	26.210	29.130	32.730	35.370	37.980
6	10.160	11.720	12.660	13.770	14.550	15.300
12	6.130	7.320	8.120	9.140	9.920	10.720
24	3.660	4.620	5.270	6.090	6.710	7.340

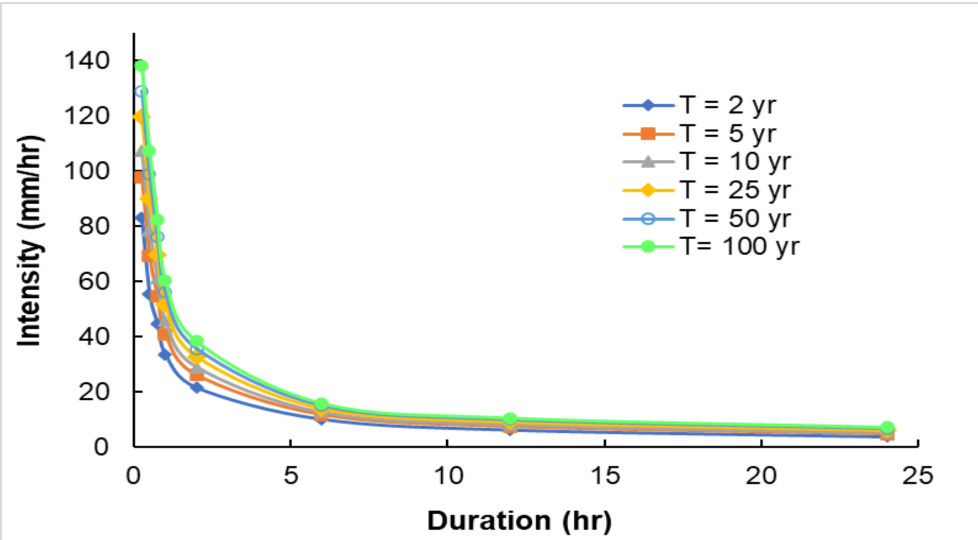

Fig. 3. IDF curves of Gainesville, GA for the duration of 0.25 to 24 hrs and six events by Gumbel distribution

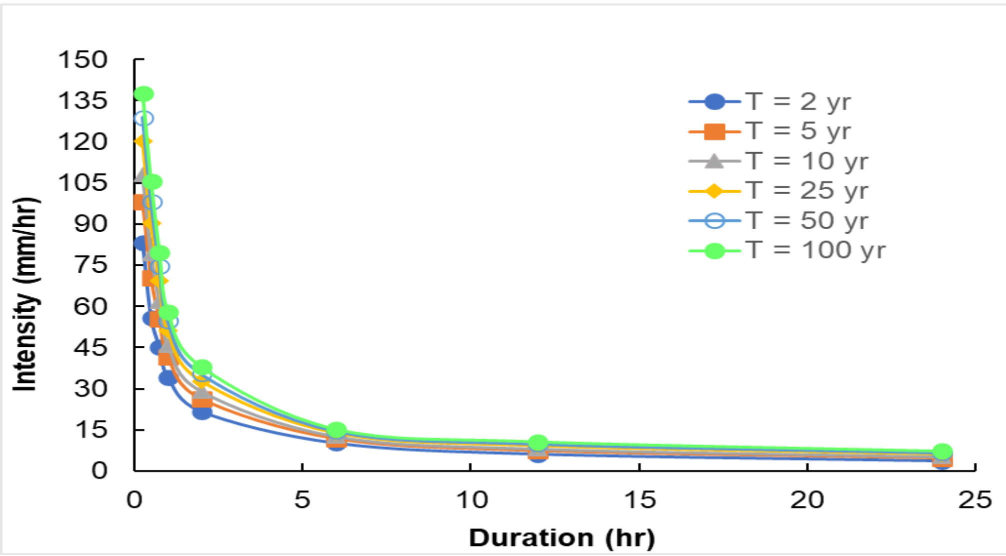

Fig. 4. IDF curves of Gainesville, GA for the duration of 0.25 - 24 hrs and six events by Log Pearson Type III model

Table 4. Results of chi-square goodness-of-fit test

Distribution	Duration in minutes							
	15	30	45	60	120	360	720	1440
Gumbel	0.281	0.700	0.716	0.572	0.906	0.700	1.566	2.844
Log Pearson Type III	0.272	0.649	0.645	0.490	0.870	0.637	1.592	2.870

The chi-square test values calculated for the Gumbel and Log Pearson type III methods show that the data fit the models at the level of significance of α = 0.05, which yields χ^2 critical < 3.84

Figs. 2 and 3 show the IDF curves obtained by fitting the Gumbel and the Log Pearson Type III models, respectively. The Gumbel and Log Pearson Type III models give maximum intensities of 138.17 mm/hr and 137.75 mm/hr, respectively at return period of 100 years with duration of 0.25 hours. The Gumbel and the Log Pearson Type III models showed that the rainfall intensity values are close to each other for almost all return periods and rainfall durations. As shown in Figs. 3 and 4 the intensity of rainfall increased with the increment in return periods but decreased with the increment in duration in any specified return period.

3.1 Chi-square Goodness-Of-Fit Test

The chi-square (χ^2) test is used to test whether the observed values (counts made from experimental data) are significantly different from expected values (counts calculated using probability theory). It is given by equation (5) below,

$$\chi^2 = \sum \frac{(O-E)^2}{E} \qquad (5)$$

Where,

O: observed value.

E: expected value.

The smaller the difference between the observed and the expected frequencies (*O* – *E*) in the equation (5), the smaller the chi-square (χ^2) will be, indicating a good fit; otherwise, it is a poor fit. Thus, a chi squared test for goodness of fit is always right tail of the chi-square distribution. The chi-squared tests were used to find out the best distribution between the Gumbel and Log Pearson type III models. Table 4 shows the results of the chi-square goodness of fit test.

4. CONCLUSION

In this study IDF curves for the city of Gainesville, Georgia for rainfall durations of 15 minutes to 24 hours have been obtained. The analyses were performed for return periods of 2 to 100years by using Gumbel and Log-Pearson Type III models. It was found that rainfall intensity reduced as the duration of the storm increased. The Gumbel and Log Pearson Type III models developed in this research are in agreement with literature theory which shows higher intensity occurring at lower duration and vice versa [20].

The chi-square values for both Gumbel and Log Pearson type III models are significantly below the χ^2 critical region and are very close at all the return periods and have the same trend, it is impossible to say exactly that one model is better than the other. More research is needed with long-term rainfall data to verify the findings obtained for the study area. The result of this study can be used by water resource planners, managers, designers, and decision makers for the city of Gainesville, Georgia.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Deger IH, Yuce MI. Rainfall intensity-duration-frequency equations for the city of gaziantep. Conference Proceeding of the International Civil Engineering and Architecture Conference. Gaziantep, Turkey. 2019;17-20.
2. Shamkhi MS, Azeez MK, Obeid ZH. Deriving rainfall Intensity–Duration–Frequency (IDF) curves and testing the best distribution using EasyFit software 5.5

for Kut city, Iraq. Open Engineering. 2022; 12(1):834-843.
3. Dar AQ, Humairah Maqbool HM, Syeedah Raazia S. An empirical formula to estimate rainfall intensity in Kupwara region of Kashmir valley, J and K, India. Conference Proceeding of the MATEC Web of Conferences. 2016;57: 03010.
4. Chitrakar P, Sana A, and Almalki SHN. Regional distribution of intensity–duration–frequency (IDF) relationships in Sultanate of Oman. Journal of King Saud University – Science. 2023; 35(7).
5. Koutsoyiannis D, Kozonis D, Manetas A. A mathematical framework for studying rainfall intensity- duration-frequency relationships. Journal of Hydrology. 1998; 206(1-2):118–135.
6. Ombadi M, Nguyen P, Sorooshian S, Hsu K. Developing intensity duration-frequency (IDF) curves from satellite-based precipitation: Methodology and evaluation. Water Resources Research. 2018;54(10): 7752-7766.
7. Mamo TG. Evaluation of the potential impact of rainfall intensity variation due to climate change on existing drainage infrastructure. Journal of Irrigation and Drainage Engineering. 2015;141(10): 05015002.
8. Lumbroso DM, Boyce S, Bast H, Walmsley N. The challenges of developing rainfall intensity-duration-frequency curves and national flood hazard maps for the Caribbean. Journal of Flood Risk Management. 2011;4(1):42–52.
9. Al-Hassoun S. Developing an empirical formula to estimate rainfall intensity in Riyadh region. Journal of King Saud University - Engineering Sciences. 2011; 23(2):81-88.
10. Nguyen VTV, Nguyen TD, and Wang H. Regional estimation of short duration rainfall extremes' Water Science and Technology. 1998;37(11):15-19.
11. United States Census Bureau. U.S. Gazetteer Files; 2022.
Available:https://www2.census.gov/geo/docs/mapsdata/data/gazetteer/2020_Gazetteer/2020_gaz_place_13.txt
(Accessed on 22 May 2024)
12. NOAA's National Centers for Environmental Information; 2024.
Available:https://www.ncei.noaa.gov/access/us-climate-normals/#dataset=normals-monthly&timeframe=30&station=USC00093621
(Accessed on 22 May 2024).
13. Gainesville-Hall Metropolitan Planning Organization (GHMPO):https://www.ghmpo.org/wp-content/uploads/2021/11/GHMPO-Planning-Area-Map- scaled.jpg (accessed 22 May 2024)
14. NOAA's (National Oceanic and Atmospheric Administration) National Weather Service Hydrometeorological Design Studies Center Precipitation Frequency Data Server (PFDS); 1959.
15. Gumbel EJ. Statistics of extremes. Columbia University Press: New York, U.S;.Chow VT; 1958.
16. Maidment DR, Mays LW. Applied Hydrology. 1st ed. McGraw-Hill: New York,U.S; 1988.
17. Mahdi ES and Mohamedmeki MZ. Analysis of rainfall Intensity- Duration-Frequency (IDF)curves of Baghdad city. Conference Proceeding of the IOP Conference Series: MaterialsScience and Engineering. 2020; 888:012066.
18. Hoggan, DH. Computer-Assisted Floodplain Hydrology & Hydraulics. McGraw-Hill: NewYork, U.S; 1989.
19. Maidment DR. Handbook of Hydrology. 1st ed. McGraw-Hill: New York, U.S;.David AO; 1993.
20. Nwaogazie, IL, Agunwamba JC. Development of Models for Rainfall Intensity-duration-frequency for Akure, South-west, Nigeria. International Journal of Environmentand Climate Change. 2019; 9(8):457–466.

Peer-review history:
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